Semi-Annual Progress Report
June 1992
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Task Objectives

The objectives of the last six months were:

1) Review and comment on proposed changes to the MODIS-N sensor specifications
2) Review and revise the MODIS-N Data Products list
3) Review and comment on the Team Leader Compute Facility plan
4) Review and comment on the Software Development plan
5) Participate in Critical Design Review for SeaWiFS data and information system
6) Review and comment on the Peer Review plan for Algorithm Development
7) Begin development of local Scientific Compute Facility
8) Initiate development of local Software Development plan
9) Analysis of sun-stimulated fluorescence data collected off northern California and prepare for 1993 field work

Work Accomplished

Sensor Performance Requirements

Several proposed changes to sensor performance were presented to the Science Team for comment. I was asked specifically to examine bands 13, 14, and 15 which have been designed for studies of sun-stimulated fluorescence. The specifications of these bands are exceptionally tight as the basic geophysical measurement of interest is extremely difficult to detect from space. The signal to noise ratio (SNR) must exceed 1000, the bands must be very narrow, and the tolerances on band position are very tight. Because of the narrowness of the fluorescence feature and the nearness of atmospheric absorption features, these bands also have strict stability requirements.

The Project requested that we examine these requirements, as they are difficult and costly to meet. I worked with Howard Gordon (University of Miami), who did much of the analysis. This consisted of testing of atmospheric models with representative field observations of chlorophyll fluorescence. I provided several technical reports that have been produced by Dr. James Gower and Dr. Gary Borstad who have collected aircraft measurements of fluorescence for over 10 years. Some minor modifications were made to these specifications, particularly in band placement, but the bulk of the requirements were retained. The fluorescence measurement will be difficult to make, and the instrument specifications cannot be relaxed if we are to meet our scientific objectives.

Project Data and Information System Plans

Data Products List

The Science Team was also asked to comment on several documents related to the data and information system aspects of MODIS-N. The first was the list of proposed data products. I modified several of my proposed products and provided updated information concerning algorithms and required ancillary data. The following products will be produced:

Chlorophyll Fluorescence Line Height

Fluorescence by the main light-harvesting pigments of phytoplankton is one of the main pathways for the deactivation of photosystem II within the cell; the other two pathways are photosynthesis (use of the absorbed quantum to reduce inorganic carbon) and heat production. It is generally thought that fluorescence and photosynthesis are competing processes such that an increase in fluorescence leads to a decrease in photosynthesis and vice versa. Thus, sun-stimulated fluorescence measurements may be used as an indicator of chlorophyll content and photosynthetic potential. As MODIS data can also be used to estimate phytoplankton biomass independently of the sun-stimulated fluorescence measurement, one will be able to express this photosynthetic potential on a per unit biomass basis. Present ocean color measurements using radiance ratios do not perform well in areas of high phytoplankton pigment concentration and high turbidity. As fluorescence is relatively insensitive to the concentration of other materials, it may be used to estimate pigment concentrations in regions where contamination by other materials is high. Remote measurements of sun-stimulated fluorescence have been made from aircraft. One of the challenges of such measurements is the relatively low signal at the wavelength of interest (685 nm). As water absorbs strongly in this region, any changes in sun-stimulated fluorescence will be small relative to the background signal. Typically, one calculates a baseline from adjacent bands and then looks at the fluorescence line height, following the method developed by Gower. Given that there is an oxygen band at 686.7 nm, the actual fluorescence measurement will be made at 681 nm. Although this will reduce the apparent fluorescence signal, this will be offset by the improved transmission through the atmosphere. The crucial baseline bands are at 667 nm and 750 nm.

Chlorophyll Fluorescence Efficiency

Using data on chlorophyll fluorescence (derived from the fluorescence line height algorithm) and independent measurements of chlorophyll a concentration (products 2571 and 2572), one can derive an estimate of fluorescence efficiency. The algorithm is simply a ratio of the two products for regions where valid fluorescence line height data can be obtained.

Chlorophyll Concentration via Fluorescence

Fluorescence line height measurements can be used to estimate chlorophyll concentration using models of the fluorescence response. These models rely on information about specific absorption of chlorophyll and fluorescence efficiency. The algorithm will be limited to those regions of the ocean that have relatively high chlorophyll concentrations (1.0 mg. m^{-3}).

Surface Primary Productivity via Fluorescence

Fluorescence line height measurements can be used to estimate near-surface primary productivity using models of the fluorescence response to changes in light, nutrients and phytoplankton species composition. These models rely on information about specific absorption of chlorophyll and quantum yields for fluorescence and carbon fixation. The algorithm will be limited to those regions of the ocean that have relatively high chlorophyll concentrations (1.0 mg. m^{-3}). The model will also be limited to regions that have at least two MODIS observations per day as the diel variability in the fluorescence response will significantly improve the estimation of photosynthesis.

Team Leader Compute Facility and Software Development Plan

The second document was the Team Leader Compute Facility plan. This was presented at the MODIS Oceans Team meeting in Miami, FL. I provided verbal comments to Al Fleig as part of the review process. The software development plan was also discussed at this meeting. Bob Evans and I have volunteered to draft a plan on behalf of the Oceans team that will cover both software development and the Oceans team compute facilities. An overview is discussed below.

Peer Review Plan

A peer review plan was developed at the MODIS Ocean team meeting. Although additional detail is required, the basic plan will consist of initial reviews this fall by members of the MODIS Ocean team. These algorithms will then be revised and presented to the SeaWiFS science team, which will consist of MODIS Ocean team members and additional scientists selected under the NASA SeaWiFS NRA. From this point, the algorithms will be described in a document that will undergo periodic review and updating, as the scientific underpinnings of the algorithm become better understood. Thus the algorithm description book will be a dynamic document and will describe not only the mechanics of the algorithm, but its scientific heritage as well.

SeaWiFS Critical Design Review

I produced a detailed list of suggestions for the SeaWiFS Project in collaboration with Bob Evans. This letter was delivered to Project and GSFC management. There was considerable room for improvement, particularly in the interface between the Version 0 Distributed Active Archive Center (DAAC), which is responsible for SeaWiFS data distribution, and the SeaWiFS project. Other problem areas were the direct broadcast reception stations and the need to rely on portable software.

Local Scientific Compute Facilities

Although only a small amount of MODIS funding was available for procurement of computing equipment, I began to assemble equipment that will eventually support my MODIS activities. These procurements were supported by funding from the EOS Interdisciplinary program by NASA Headquarters. The system (shown in Figure 1) relies on massively parallel computers as the main compute engines. These are connected via a high speed network to other devices that provide specialized services, including data base management, archiving, visualization, and other networked services. Although these machines will be used primarily for ocean modeling as part of my interdisciplinary research, the machines have been sized to accommodate the MODIS algorithms. Much of the basic ocean color/atmospheric algorithms lend themselves naturally to a parallel environment. As the next generation of FORTRAN (FORTRAN-D or High Performance FORTRAN) will be designed for parallel constructs, it is appropriate to begin the process of moving the algorithms from conventional, serial architectures.

The massively parallel machines consist of a Thinking Machines CM-200 with 8192 processors, 1 GB memory, and 10 GB of high-speed disk. This will be replaced later this year by a 32-processor CM-5, which will be roughly three times as fast (1.5 Gflops) and have twice the disk storage. I have also established a research partnership with IBM to explore their planned massively parallel products. Initially, this consists of a cluster of IBM's RS/6000 workstations and the appropriate software to run code in parallel across multiple processors. This configuration will evolve over the next three years as IBM products are developed.

I am examining various archive strategies, including specialized file servers (such as Auspex) and RAID (Redundant Array of Inexpensive Disks)
systems. However, no decisions have been made yet, but the system needs some type of hierarchical file storage that can accommodate at least 100 GB. I expect that a decision will be made in the next year.

Visualization is being handled by a set of specialized machines including a Silicon Graphics 320 VGX, a Hewlett-Packard 750 CRX, and a Macintosh Quadra 900. Unfortunately, scientific visualization requires a wide range of hardware and software. The SGI machine will also host SeaWiFS processing software that is being developed jointly by University of Miami and GSFC. The HP also runs Global Imaging software for processing satellite imagery. I have been investigating various visualization tools to incorporate into these processing systems, which are described below in the software plan.

I presently manage a 20 GB archive of processed CZCS and AVHRR imagery on a HP workstation, using Ingres as the relational data base system. I am upgrading the HP to a Sun 690MP with 128 MB memory and 5 GB of high-speed disk. One option is to upgrade the Ingres license and continue to use a relational data base. However, this method does not fulfill many of the basic requirements for scientific data bases, such as the ability to search for data based on relationships between data sets (i.e., content-based searches). I am exploring with Hewlett-Packard the possibility of using their advanced object-oriented data base technologies.

Other services (mail, network, file servers, etc.) are provided by a suite of College-managed machines, and the EOS/MODIS SCF will simply be one component of the overall system. A new wing is being added to the Oceanography building to consolidate all of the present and planned hardware.

Lastly, a wide range of desktop machines are being purchased for local analysis and display. These are generally small UNIX workstations, such as Suns. However, I have procured several NeXT workstations (with both EOS and MODIS funds) to explore object-oriented design.

These compute resources will be shared with MODIS researchers at the University of Miami as part of their algorithm development activities.

Software Development and Data Plan

I have just begun to define these elements in detail. As mentioned above, Miami researchers will be working with our massively parallel computers to explore the feasibility of porting existing ocean color code to parallel machines. The increased compute power and larger memory will allow new methods of data processing to be developed. For example, the various free parameters could be adjusted in real time to observe the behavior of the various geophysical products in parameter space.

The more complex algorithms of MODIS will require more sophisticated tools for visualization and analysis as part of the quality control process. Simple limit checks will still play a role, but visualization tools where researchers can explore large volumes of data as a function of changes in parameters will be necessary. I have begun to examine the various visualization tools that are available, such as Khoros (University of New Mexico) and Explorer (Silicon Graphics). As none of these applications is complete, I am developing modules that could provide links between them.

The MODIS Oceans team feels that object-oriented techniques will eventually play a role in MODIS algorithm development. I have begun to examine C++ and Objective C as candidate languages. An initial test was made using Macintosh Hypercard as an object-like environment.

As mentioned above, Bob Evans and I are working on a software development plan for the Oceans team. The overall plan is to develop a framework at Miami with assistance from OSU. This framework will be at least "object-like" if not completely object-oriented. This will allow other Oceans team member to provide modules based on a consistent, well-defined set of interfaces. A true object-oriented approach would maximize software reuse as well as provide a more robust system for maintenance. We expect to have an initial draft later this year.

Data Analysis and Interpretation

A drifter equipped with bio-optical instrumentation was deployed twice in the California Current. I have completed the data analysis and I am presently preparing a manuscript for submission to the Journal of Geophysical Research. Part of the instrumentation included measurements of sun-stimulated fluorescence at 683 nm. In Figure 2, I compare various estimates of chlorophyll, using sun-stimulated fluorescence, strobe fluorescence, beam transmission, and downwelling irradiance. The strobe fluorescence measurements were calibrated against chlorophyll extractions of water samples. In the first deployment (1987), the sun-stimulated fluorescence agrees fairly well with the strobe fluorescence measurements, using the model developed by Kiefer et al. [1989] and Chamberlin et al. [1990]. The free parameters in this model, specific absorption of chlorophyll and the quantum efficiency of fluorescence, were set at 0.04 and 0.045, respectively. However, the comparison between the two fluorescence measurements was poor in the second deployment in 1988 (Fig. 3). I adjusted the specific absorption coefficient and the fluorescence quantum efficiency based on other measurements reported in the literature (specifically, Kishino et al. [1984]) and noted that the correlation between the two fluorescence measurements was significantly better (Fig. 4).

There are two conclusions relevant to MODIS. First, the accuracy of the chlorophyll measurements derived from sun-stimulated fluorescence will likely be no better than about 20% for a wide range of chlorophyll concentrations. Second, the existing models have considerable variation, in large part because of the changing bio-optical properties of the phytoplankton. Note that the correlation between the chlorophyll estimates is much better nearshore than offshore. This is likely the result of the dramatic changes in phytoplankton species composition which occurred as the drifter moved from the nearshore region dominated by chain-forming diatoms to the offshore region dominated by dinoflagellates and single-cell diatoms. This change in the bio-optical properties of the phytoplankton probably explains the differences in the fluorescence model parameters used in 1987 versus 1988. The change in pigment packaging [Bricaud et al., 1988; Carder et al. 1991] is well-known and will contribute to the error of the fluorescence-based chlorophyll estimates. However, with the increased number of bands of MODIS, it may be possible to back out information on the scattering properties of the phytoplankton by comparing the traditional color ratio method and the fluorescence method.

I also used the sun-stimulated fluorescence data to estimate instantaneous primary productivity using the model of Chamberlin et al. [1990]. Figures 5 and 6 show these data from 1987 and 1988. Unfortunately, there were no direct measurements of primary productivity to compare with these estimates. However, in 1987 I was able to use beam transmission data to estimate growth rates based on changes in water transparency. I followed the methods described by Siegel et al. [1989] to estimate daily productivity. Table 1 shows that both methods were in rough agreement. However, as pointed out by Cullen et al.[1992], beam attenuation can change as a result of changing optical properties of the phytoplankton. Thus there is considerable uncertainty as to whether the productivity estimates are useful. As fluorescence properties near the surface of the ocean can change rapidly as a result of the high levels of solar radiation, considerable field work must be done before we can use sun-stimulated fluorescence with confidence. Many of the existing models, such as Chamberlin et al. [1990] work best in light-limited conditions deep in the water column. MODIS measurements of fluorescence will be limited to near-surface, high light conditions so new models may need to be developed.

Anticipated Future Actions

I am coordinating efforts by the Oceans team to develop a comprehensive plan for ocean color observations for the next ten years. With the launch of SeaWiFS next year, followed by OCTS in 1996, MODIS and EOS-Color in 1998, and a second MODIS sensor in 2000, there will be a ten-year time series of ocean color. However, there are several managerial, scientific, and technical issues that must be resolved. For example, how will data be accessed and merged? How will the different sensors be calibrated and algorithms validated? How will scientific requirements be translated into sensor design? This report will lay out a road map to address these and other issues.

Under funding by the Office of Naval Research, I will be deploying 24 drifters next year in the California Current. These drifters will be equipped with spectroradiometers that will measure upwelled radiance at the SeaWiFS wavelengths as well as at 683 nm (fluorescence). Although the focus of the work is on the relationship between bio-optical properties and mesoscale ocean circulation, I plan to collect some primary productivity data to compare to the fluorescence measurements. The drifters should operate for nearly three months, covering a wide range of oceanic conditions.

I expect to complete the archiving and networking portion of my SCF in the next 6 months. I will also complete an initial software development plan, in collaboration with Bob Evans. Together we will begin work on implementing SeaWiFS algorithms on massively parallel machines. We will also cooperate on integrating visualization tools into the processing stream for both data analysis and quality control. We will use SeaWiFS data as a testbed for this activity. I will also explore advanced pattern recognition techniques for cloud masking.

This will be based on neural net technology, implemented on the CM-200. Initially, I will use these methods on my archive of AVHRR imagery.

Problems and Solutions

Initially, my programmer worked on object-oriented coding. However, it soon became apparent that this individual was not up to the task. With his departure, I have just begin a search for a replacement. Although this has resulted in a minor delay, in the long run this should greatly improve the overall project. I am hoping to hire someone experience in object-oriented data bases and programming who can work on coupling the data base with the processing and visualization activities.

My research is hindered by lack of funding for a postdoctoral researcher who could provide valuable assistance with the scientific aspects of this project. Unfortunately, I cannot provide full-time attention to this work because of other commitments, and another researcher could give the attention that is needed. If funding profiles continue as planned, I should be able to add such a person sometime in the next 2 years.

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